

# **Trans-Interface Optical Communication (TIOC)**

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## **LONG-TERM GOALS**

The goal of our proposed work is to develop a system for optical communications through the sea-air interface and to provide a predictive, performance model for the system for different environmental conditions, source power levels, receiver range, etc.

## **OBJECTIVES**

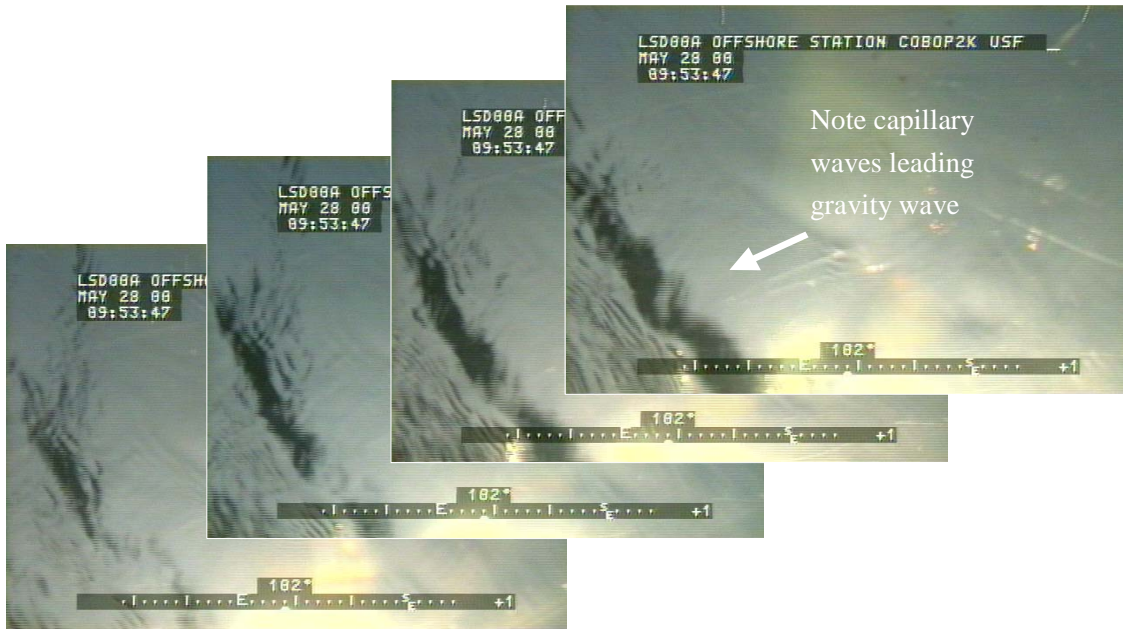
The scientific objectives of the project involve understanding the spectral and temporal effects on trans-interface communication of water constituents and surface characteristics. The engineering objectives involve the development of a system that will utilize digital signal processing (DSP) of video imagery to identify the positions of redundant sources within the imagery (areas of interest, AOIs) and control a MEMS device (Texas Instruments Digital Light Processor, DLP) to direct radiance from only the AOIs to a high-speed sensor (e.g. PMT, APD) for demodulation.

## **APPROACH**

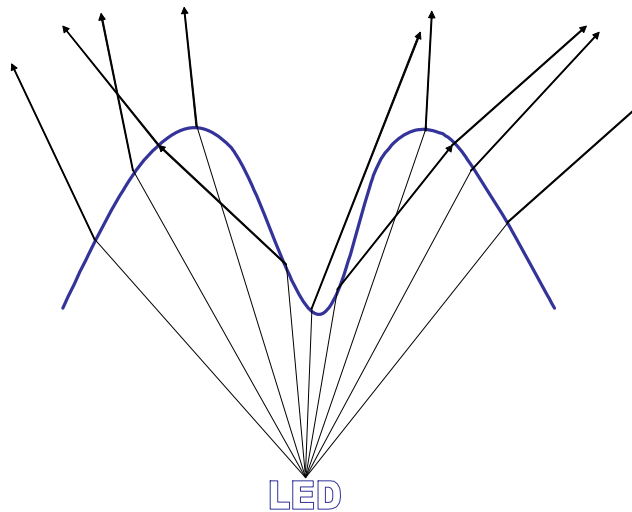
Wave refraction of light rays passing through the sea-air interface causes a perturbation in the path of the ray relative to its position and direction for a flat sea surface. While gravity waves range in slopes up to about 15° (e.g. Lighthill 1980), these slopes can be augmented near the crests by parasitic capillary waves (Martin 2004; also see our data, Figs. 1, 2, acquired in Exuma Sound). According to the Cox-Munk (Cox and Munk 1954) wave-slope relationship to wind speed, a wind of 10m/s results in a mean wave slope of about 0.19. Wu (1990) suggests a more rapid increase of slope with wind speed, however. Past experience in trying to avoid sun glint when performing remote sensing operations indicates that slopes of 0.6 are not unusual for individual waves.

For capillary waves, the disruption in directionality of an optical beam or ray that results in information dropouts can be significant. This is corroborated by an experiment made in Bayboro Harbor (St. Petersburg, FL) where the continuity of signal from a single LED is contrasted against that from up to four LEDs (see RESULTS). Here, four LEDs are separated by four feet at the corners of a square frame approximately 1 foot below the interface. Generating capillary waves with 2 air jets provides enough capillary wave activity to provide significant signal drop-outs.

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***Figure 1. Video sequence from underneath the sea surface (0.25 m depth) showing wave train development. Note the group of capillary waves leading a gravity wave.***



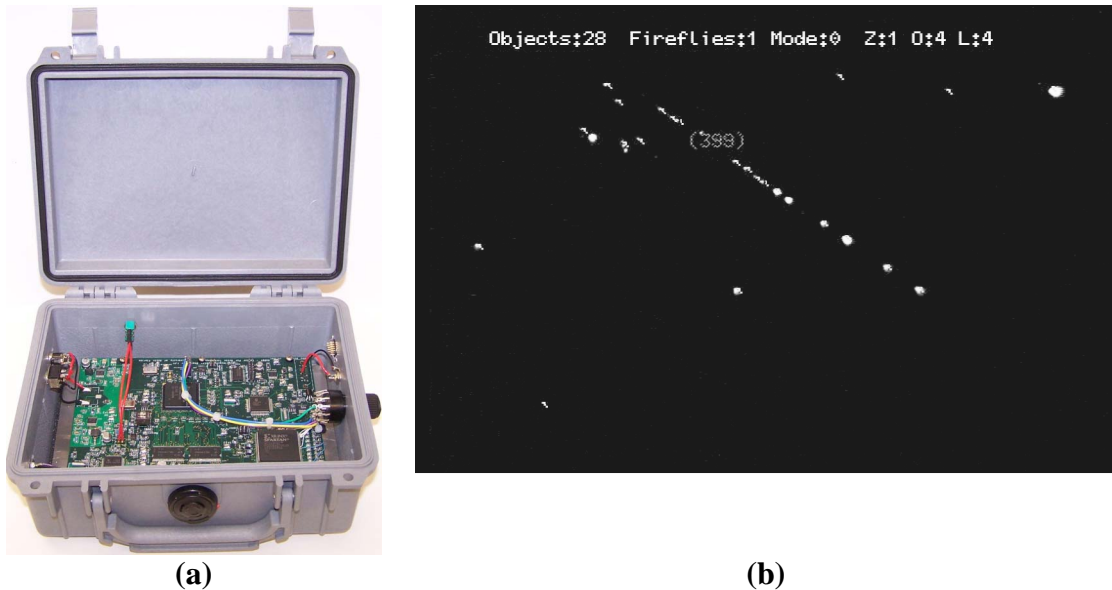
***Figure 2. Ray-tracing schematic demonstrates that capillary waves bend light in a manner that creates temporal “holes” in direct viewing angles that would interfere with communication modulation***

In this concept for optical communication through the air-sea interface, multiple emitters are placed beneath the water’s surface and imaged from above. These emitters appear as small points of light in a video image of the area. In a project funded by Blackbird Technologies, we have demonstrated the ability to process video in real-time and identify our emitters within the video. For this work, we

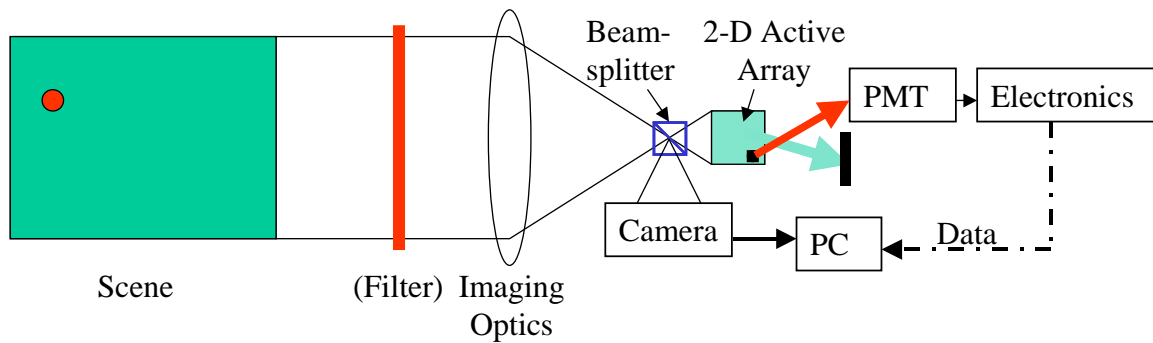
designed optical emitters using LEDs that transmit data using on/off keying. Since standard video rates are used, data bandwidth is limited to 5 baud and only short messages containing emitter ID information is transmitted.

Utilizing digital signal processing (DSP) hardware, we developed a system that processes NTSC video, identifies sources within the video matching search criteria, decodes data transmitted by those sources, and outputs the input video signal with graphical overlays highlighting the detected signals and displaying received data. Figure 3 shows the prototype electronics (a) and a screen capture from a video clip (b). The screen capture shows several sources of light imaged through a narrow band-pass filter. For the case shown, only one point of light is actually a device (ID 399) communicating data. The other points are street and car lamps with energy in the pass band of the optical filter. Without our DSP approach, these other points would not only decrease S/N but could be identified as spurious targets. We have demonstrated the ability to maintain detection of signal sources under a wide range of environmental conditions, have demonstrated tracking of moving signal sources, and proven our ability to distinguish our devices from sources that may appear similar in nature.

This extension of the basic system involves the use of a spatial modulator to optically direct only the portions of the image containing signal sources to high-speed detectors for data reception. This concept is illustrated below in Figure 4. Any camera outputting NTSC video is used to image the scene of interest. The video signal is processed by the DSP electronics to determine the coordinates of signal sources. These coordinates are used to control an active modulator to direct only the portions of the image containing signal sources to a high-speed detector, reducing background noise and raising the signal-to-noise ratio.



***Figure 3. Prototype electronics used to process video signals to locate and decode optical signals, and a representative screen capture showing the detection of a signal source placed near many noise sources.***



***Figure 4. Actively-steered high-speed, high sensitivity detector. 2-D Active Array (Eg. TI DLP) is used to actively project only areas of the scene of interest onto a high speed, highly-sensitive PMT detector.***

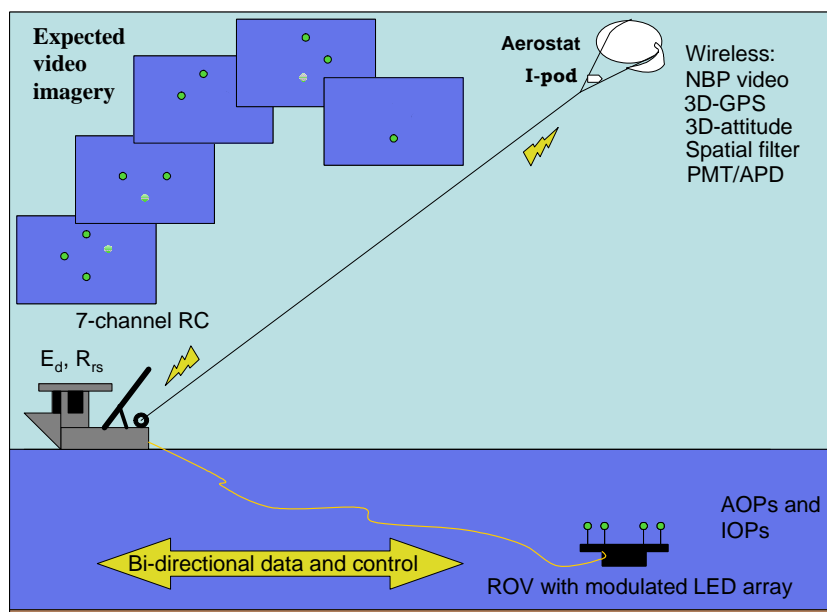
MEMS 2-D imaging arrays are commercially available and widely used in TV and data projection systems [eg. Texas Instruments Digital Light Processor (DLP)]. The digital mirror device (DMD) is designed to tilt each of several million mirrors into 1 of 2 positions according to a video image received by the coupled electronics module. In the first(default) position the mirrors are turned off and are all coplanar. Incoming radiation is simply reflected at the same angle as the incoming beam (relative to the surface normal). In the second position, the mirrors are tilted by approximately 7 degrees. Depending on the orientation of the DMD, the reflected beam can either be at a larger or smaller angle (by 7 degrees) than the beam reflecting off the mirrors in the first position. Thus, by turning the appropriate mirrors on or off, light from specific portions of the image can be separated from other regions. It is proposed that such a 2D DMD array be utilized within a custom optical system to allow simultaneous targeting of each of the individual sources that comprise the underwater transmitter. Only those mirror elements corresponding to the locations of the signals will be energized to redirect the signals to the high-speed detector. As wave action and other factors interfere with the reception of an individual source, the corresponding mirror elements will be turned off and only light from the other valid sources will continue to the high-speed detector. In the best case, all individual sources will be present and their combined energy will be directed to the detector for maximum signal to noise. Note that by rejecting residual background image noise due to reflected skylight or sun glint, the gain on the high-speed detector can be increased.

Finally, in collaboration with the USF Center for Optical Observability and Communications, we have assembled a suite of instrumentation and platforms (Figs. 5 and 6) to make field measurements of a multi-spectral, LED array from various altitudes. Measurements from the surface, airborne, and submerged vehicles will be used to refine and validate a model of the modulation rates possible to achieve in various environmental conditions.

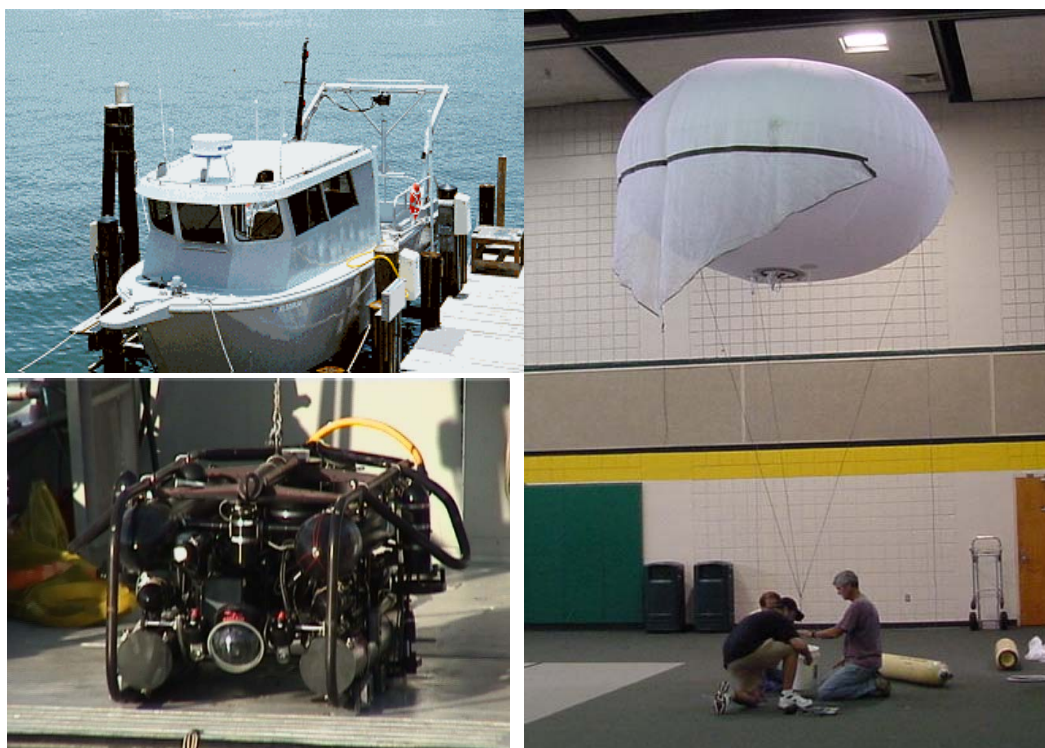
## **WORK COMPLETED**

A single-wavelength (525 nm), 4-source, LED array was constructed and deployed in both day and night field tests (see Figures 7 and 8). Analysis of the data acquired during these deployments indicate





**Figure 5.** *Cartoon showing envisioned field experiment strategy. The R/V Subchaser will act as the mother-ship for our airborne and underwater remotely operated vehicles. Without the aerostat (TOPO-13), field operations would be prohibitively expensive.*



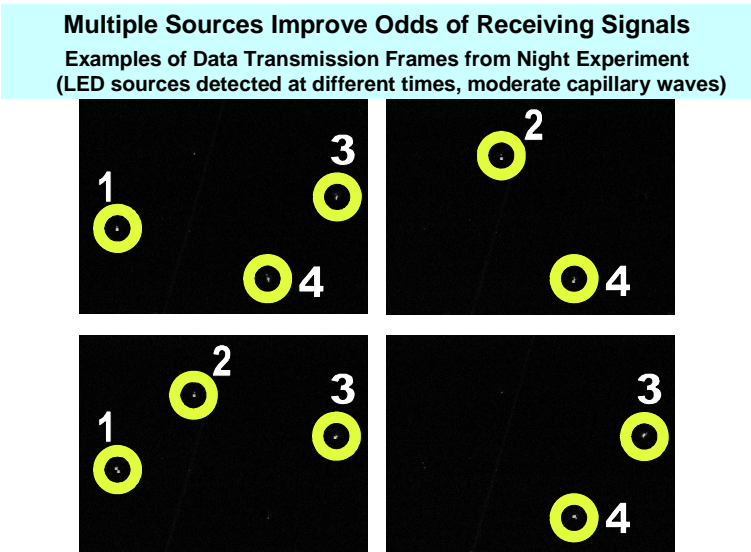
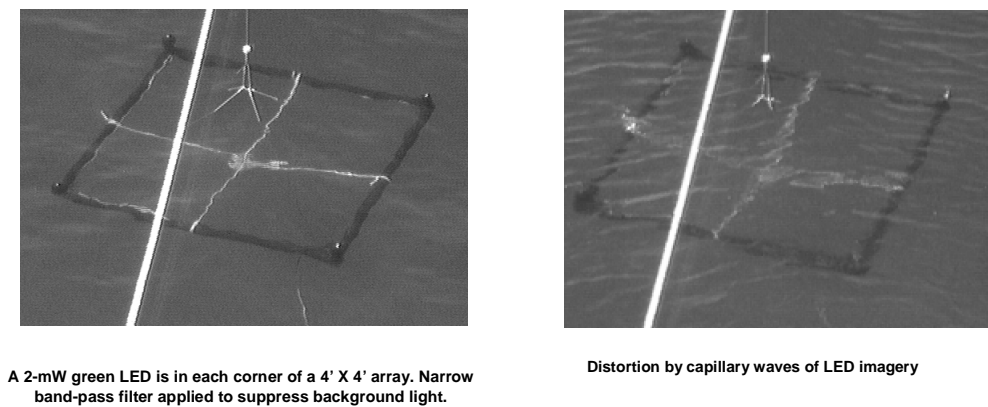
**Figure 6.** *The R/V Subchaser (upper left) will support two remotely operated vehicles for field operations. The ROSEBUD ROV (lower left) will carry a modulated LED array and make AOP and IOP measurements. The 13-foot Tethered Observability Platform for Oceanography (TOPO-13, right) will observe the ROV from various altitudes and acquire transmitted optical data.*

that the basic hypothesis is correct and that our envisioned approach is viable. Design and control strategies for a 4-channel, 4-source array has been completed and construction is underway.

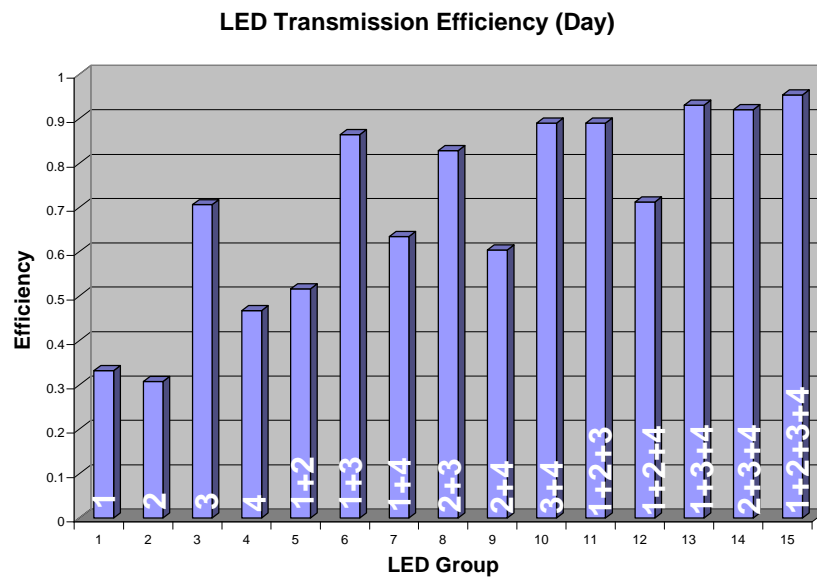
Licensing arrangements with Texas Instruments for use of the DLP have been completed.

**RESULTS**

As expected, our hypothesis that redundant sources would increase transmission efficiency proved true in both daytime and nocturnal field tests. These experiments utilized only narrow-band-pass and polarization filters and improved efficiency by more than a factor of three (see Figures 7 and 8). When completed, spatial filtering is expected to increase the signal-to-noise and thus range and/or data rate by a factor equivalent to the ratio of the total image area divided by the sum of the LED-neighborhood areas of the images (e.g. > 20X).



*Figure 7. Images of the LED array with and without induced capillary waves (top) and examples from processed imagery (bottom) showing the drop-out of various sources in various frames.*



**Figure 8. Statistical analysis of the various permutations of the four, redundant, LED sources. Transmission efficiency increased to 95% utilizing all four sources versus 30% utilizing a single LED.**

## IMPACT/APPLICATIONS

There are many scenarios where communication between a submerged asset and an airborne asset would be very desirable. However, communication through the air/sea interface is, at best, problematic and any high-bandwidth communication strategy remains elusive. Field tests of our basic approach, that is, utilizing narrow-band-pass and polarization filters, but not yet with spatial filters, have shown that our hypothesis is sound, transmission efficiency increased by over a factor of three. With the addition of the DPS and MEMS DLP technology, we expect a further, **very significant increase in S/N**. This technology should not only make optical communication through the air/sea interface feasible but also allow for high-bandwidth communication.

## RELATED PROJECTS

- USF College of Marine Science Center for Underwater Observability and Optical Communication – Utilization of the ROSEBUD ROV and the TOPO-13 air platform
- Eric Kaltenbacher, SRI International – DSP processing and DLP MEMS device

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